ation for the Advancement of Science for a grant used in connection with the 1915 measurements.

[1] Bauer, L. A., On gravity determinations at sea, *Amer. J. Sci.*, **31**, 1 (1911). Hecker's remarks on ocean gravity observations, *Amer. J. Sci.* **33**, 245 (1912).

[2] Bowie, Wm., Isostasy and the size and shape of the earth, *Science*, **39**, 705 (1914).

[3] Hayford, J. F., these PROCEEDINGS, **2**, 394 (1916).

[4] For a description of the apparatus employed by Hecker and a summary of his ocean measurements, see Hecker, O., Bestimmung der Schwerkraft auf dem Schwarzen Meere und, an dessen Kuste sowie neue Ausgleichung der Schwerkraftmessungen aud dem Atlantischen, Indischen, und Groszen Ozean, *Zentralbur. Internat. Erdmessung, Veroffentlichungen Berlin*, N. F., Nr. 20 (1910).

[5] *Washington, D. C., Bull. Bur. Standards*, **3**, 663 (1907).

[6] This principle has already been employed by Mascart, [*Paris, C. R. Acad. Sci.*, **95**, 631, 1882], who used a sealed-off barometer of the U-tube type. The temperature was not controlled, and volume and pressure were both variable. The gas volume had therefore to be measured, the pressure corresponding to the observed temperature and volume calculated, and finally reduced to standard conditions.

[7] This procedure now seems undesirable, since Pernet has observed a departure of 0°.01C. from the true zero when the bulb of a thermometer is surrounded by artificial ice freely drained, due to the ice being undercooled. (See Pernet, J., Sur les moyens d'eliminer l'influence de la variation des points fixes des thermometres a mercure. *Travaux. Bur., International des Poids et Mesures*, 1881, second partie.) In the writer's measurements, ice was added in small quantities at frequent intervals so as to keep the tanks completely filled, and remained in the apparatus for several hours before melting sufficiently to sink to the level of the gas chamber. It is consequently doubtful whether the effect observed by Pernet influenced the measurements, but it is a possible source of error which can be avoided by keeping the interstitial spaces filled with water.

[8] *Phil. Trans. R. Soc., London*, **196**, 205 (1901).

[9] *Loc. cit.*

[10] The above procedure was not followed strictly in the trials of the apparatus which have so far been made at sea, due to the difficulty of following the observing tube with the eye when the ship is rolling in a heavy sea. Experience shows however that such an arrangement is necessary if observations are to be made in rough weather, and the difficulty in observing can apparently be met by a modification of the viewing apparatus.

[11] See Hecker, *loq. cit.*

THE PROBLEM OF CONTINENTAL FRACTURING AND DIASTROPHISM IN OCEANICA

By Charles Schuchert

DEPARTMENT OF GEOLOGY, YALE UNIVERSITY

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Paleogeographic studies during the past thirty years have been developing the hypothesis that the ancient continental platforms were arranged latitudinally rather than longitudinally as they are now, and, further, that their areal extent, including their emergent and submerged portions, was greater than at present. It appears that vast land-masses have been fractured, broken up, and more or less permanently taken

possession of by the oceans, a history which none exhibits better than the Australia-New Zealand region.

We have learned from the several deep-sea expeditions something of the rare and strange life of the oceanic abysses. An analysis of these organisms shows that no Paleozoic forms occur among them, and very little of the life indeed is ancestrally traceable even to the stocks of Triassic times. It is with the Jurassic and later life that the organisms of the abysses have their affinities. This seems to indicate that the oceans have been progressively deepened only since the Triassic. As one of the most marked crustal deformations, however, began in the Coal Measures of the Paleozoic and continued, though with pauses, well into the Triassic, it therefore appears that the oceans have been progressively enlarged and deepened ever since Permian time. This is in keeping with the theory that the earth's radius has been gradually diminishing and that the compensation therefor has been greatest in the oceanic basins, the areas of greatest rock densities.

It is now more than fifty years since James D. Dana began to teach that the rising continents and the sinking oceanic basins have been, in the main, permanent features of the earth's surface. He did not mean, however, that the continents have always had essentially the same shape, elevation, and areal extent that they have today. Still, Dana did not fully appreciate the amount of continental fragmenting that has taken place in the course of geologic time, though he clearly pointed out the foundering of Australasia, speaking of it in his famous *Manual of Geology* (p. 797) as "a fragment of the Triassic world." The teachings of Dana as to the permanency of continents and oceanic basins have been accepted in some form by all geologists, and lie at the basis of all zoögeography and evolution as well. Geologists are holding more and more to the hypothesis that the earth periodically shrinks, and each time it does so some parts or all of the continents may rise, but that in the main there is subsidence of the ocean bottoms, that the water of the hydrosphere is constantly increasing in amount, and that even though the continents are in the main permanent, yet they are partially breaking down into the oceanic basins.

From this we conclude that the enlarging oceanic basins are the most permanent features of the earth's surface. On the other hand, along with the progressive subsidence, the bottom of the Pacific is also built up into many local volcanic cones by outpourings of lava, and, further, it rises into more or less long mountain ridges. Some of these elevations of the bottom appear at the surface of the ocean as groups or lines of dead or active volcanoes. Another general conclusion is that most of

the "deeps" of the Pacific Ocean situated between 18,000 and 31,800 feet beneath the surface occur near the continents that exist now or existed formerly, or that they are located on the outer or oceanic side of mountain chains. These, the "foredeeps" of Suess, are striking tectonic features of the lithosphere. As for the true limits of the Pacific Ocean, Suess states that they are seen in the trends of long mountain folds. "So it is from New Zealand and New Caledonia to the borders of eastern Asia, to the Aleutians, and all along the western coast of both Americas."[1]

So far we have been considering the problem of crustal depressions essentially from the standpoint of hypothesis; now let us see what is actually known as to the topography of the Pacific Ocean and the geologic history of the Australasian region. An excellent summary of the present geography of the Pacific Ocean and the topography of its bottom is shown on the splendid map by Max Groll, recently published by the Institut für Meereskunde of the University of Berlin (1912). This map is based on Lambert's equal-area azimuthal projection, with a replotting of all geographic and bathymetric data ascertained up to January 1912, and is therefore more up-to-date and far better than any heretofore published. Groll states that he considered at least 15,000 soundings, made in all the oceans, and that yet there are many areas in the Pacific, hundreds of miles across, without a single one. It is therefore natural for him to add: "The greater part of the Pacific Ocean is still unexplored. . . . One is actually frightened at the little that is yet known of the bottom relief of the oceans and at the few data on which our representation of it is based. . . . Even in so relatively well known an area as the East Australasian seas, there are rarely more than from four to six deep-sea soundings to each five-degree field." Our detailed knowledge of the actual configuration of the bottom of the Pacific is therefore seen to be very slight indeed.

Let us now review the larger features resulting from the ancient cycles of aërial erosion and marine deposition through which has been determined the paleogeography of Australasia. An analysis of this history since the Cambrian seems to show that at least two northeasterly trending troughs of sedimentary accumulation began to form early in the Paleozoic. The western one, which may be known as the Tasman trough, almost wholly of Paleozoic development, is now partially elevated into the plains and mountains of eastern Australia, while the rest of it has sunk deep into the present sea, and with it considerable of what was formerly western New Zealand. The other, or eastern trough, which also appeared early in the Paleozoic, maintained itself after this

era in diminished extent throughout the Mesozoic and even into Pliocene time. This may be known as the New Zealand trough, a far narrower but much longer one than that of Australia; the shorter southern portion has now risen into the mountains of New Zealand, while the far longer northern part has apparently subsided to a depth of not more than 9000 feet, forming a submerged plateau upon which stand the volcanic islands of the Kermadecs and the Tongas.

In the New Zealand trough there appear to be, according to Park,[2] no less than 45,000 feet of Paleozoic and 11,000 feet of Mesozoic sediments, all of which are apparently of marine origin. These are coarse in grain and have much interbedded igneous material, which indicates that the adjacent lands were unstable and repeatedly reëlevated into high lands. There were at least four times when the New Zealand trough was markedly subject to folding and uplift; these were toward the close of the Silurian, Devonian, Jurassic, and Cretaceous periods. During the Tertiary, the New Zealand trough also appears to have been in continuous subsidence from late Eocene into Pliocene time, when about 9000 feet of marine sediments had been laid down along the eastern sinking margin. Late in the Pliocene there was marked vertical uplift, probably as much as 4500 and possibly even 6000 feet. The nearly horizontal Tertiary strata are now found in places at an elevation of 3000 feet, having been depressed 1500 feet during the time of Pleistocene glaciation. The high condition of New Zealand at this time united into a greater New Zealand all of the present outlying islands of the New Zealand plateau, no part of which is now submerged more than 3000 feet.

In Australia there is no evidence of the Tasman sea during Cambrian time, for the marine invasions at first are from the south and later across the entire medial portion of the continent. The trough begins to appear as a sea-way in the Ordovician (?5000 feet of deposits, according to Süssmilch[3]), with the greatest time of subsidence during the Devonian (27,000 feet); it continued with some interruptions throughout the Carboniferous and Permian (36,000 feet). During the Paleozoic, about 70,000 feet of essentially coarse sediments and interbedded volcanics were laid down in New South Wales, though smaller thicknesses seem to prevail elsewhere in eastern Australia. Here again we see the geologic results of high adjacent and often rejuvenated western lands. The record also shows that there were in Paleozoic time at least three periods of decided crustal folding (Ordovician, Silurian, and Devonian), and one of vertical uplift with faulting (during the close of Permian time). Following the Permian deformation, the continent was repeat-

edly lifted above the embrace of the Tasman sea, and most markedly so in the Pliocene, when all of eastern Australia was vertically elevated and block-faulted between 1500 and 7300 feet above sea-level (during the 'Kosciusko epoch'). In compensation for this elevation the Tasman sea sank, as now there are great depths close to the continent, in one place going down to 18,500 feet.

Australasia has been the most remarkable asylum among the continents for the preservation to this day of living examples of the plants and animals of the medieval world. Among these in great variety are the marsupial or pouch mammals, and the far less diversified, more primitive, but more remarkable egg-laying monotremes. The marsupials were at their culmination in the Pliocene, when forms existed larger than any living rhinoceros (*Diprotodon australis*). From the chronogenesis of these stocks and their diverse evolution in Australia, we learn that they must have been on that continent long before, and that they had been free from all Asiatic invasions and therefore escaped destruction by the higher, more intelligent carnivorous placental mammals. We must therefore conclude that Australia has been an island continent at least since late Eocene time, for it is since then that the placental mammals have elsewhere dominated all other land life.

The question next arises, When was Australia severed from Asia? From the paleogeography as now deciphered, we learn that Asia and Australasia were in complete connection throughout the early Paleozoic to the close of the Devonian. In Lower Carboniferous time, however, southeastern Asia began to be invaded by the Indian and Pacific oceans in the region of what are now the East Indian Islands. A greater subsidence here and in New Guinea, New Caledonia, and elsewhere in Australasia began in the Jurassic and probably persisted well into Cretaceous time. However, from the fact that carnivorous dinosaurs—land reptiles that arose either late in the Permian or shortly afterward—are known in the Triassic of Australia (none at all occur in New Zealand), we must conclude that there were still at this time intermittent land-bridges connecting this continent with Asia. The time of complete severance apparently came in the Jurassic, and the trough of separation seems to be the present Molucca-Banda sea, which has depths varying between 4650 and 21,100 feet.

Finally we must ask, When did the thousands of oceanic islands—the Oceanides—arise? They are probably in the main of volcanic origin and occur singly, in groups, and most abundantly in linear arrangement. The isolated and the grouped islands probably all represent great volcanic cones that have built themselves up from the ocean

bottom through the eruption of rock material. What is the origin, however, of those that are arranged in linear series? Are they ranges of volcanoes that have likewise grown from the depths but are situated on lines of fracture in the lithosphere, or do they rest on the crests of great arches or foldings of the ocean bottoms? Equally important questions are: What is their geological history, and have they simultaneous or successive origins? So far as known, none of the smaller oceanic islands reveals fossils older than the later Tertiary, a condition that appears to be in harmony with the theory that the sum of their movements is negative and thus in keeping with the idea that the oceanic bottoms are subsiding areas. We have as yet little to show when they originated, and still on the basis of the periodically recurring diastrophism it would seem that none can be older than the Permian, a time of intense and world-wide crustal deformation. Others may have originated during the late Cretaceous crustal movements, and all may have again been reëlevated and stirred into volcanic activity with the world-wide crustal readjustments that began in the Miocene and continued into late Pliocene time.

The views just presented are those of most paleontologists, but there are geologists and zoögeographers who do not accept the idea of continental fragmenting taking place on so large a scale as is here indicated. They hold firmly to the theory of the permanency of continents and ocean basins, believing that these positive and negative elements of the earth's surface have always retained the forms they now have. In their eyes, the physical evidence in the areas of fragmentation, and especially in the southern hemisphere, is not of a nature to compel the view that large lands formerly existed here, and they say, further, that there is no process in the mechanics of the earth known to them that would account for such down-breaking of the lithosphere.

As for the ancient life found in Australia, those who hold the above view say that we are still too ignorant of the world's organisms and their histories to conclude from them that their asylums were formerly connected with other land-masses, or they hold that the animals reached these places by accidental dispersal, through the air or by being rafted across the intervening water areas. Hence this conflict of views marks one of the greatest outstanding problems of geology and paleontology. The writer, however, is overwhelmed by the facts revealed in the geographic distribution of ancient and modern animals, and is compelled to dissent from the rigid view of the permanency of continents.

To sum up, in conclusion, we may say that the bottom of the Pacific Ocean in the region of greater Australasia seemingly became more and

more mobile with the Lower Carboniferous and especially during the Jurassic and Cretaceous. During this very long time, the eastern half of the continent, a land about 1800 miles east and west and 2200 miles north and south, nearly all went down more and more beneath the level of the sea to a maximum depth of about four miles and an average depth of between one and two and a half miles. Further, the entire area of the Oceanides also subsided, and possibly to an equally great depth; while this was taking place the bottom was apparently folded and built up by volcanic material into many more or less parallel ridges, a series of arcs extending over an area of about 3500 miles east and west and the same distance north and south. Finally, we may add that the entire western half of the Pacific bottom appears to be as mobile as any of the continents of the northern hemisphere, with the difference that the sum of the continental movements is upward, while that of the ocean bottoms is downward. This paper will be published at greater length and with illustrations in the *American Journal of Science.*

[1] Suess, *Natural Science*, 2, 180 (1893).
[2] Park, *Geology of New Zealand*, 1910.
[3] Süssmilch, *Geology of New South Wales*, 1911.

THE PETROLOGY OF SOME SOUTH PACIFIC ISLANDS AND ITS SIGNIFICANCE

By Joseph P. Iddings

BRINKLOW, MARYLAND

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Petrology as a more comprehensive term than petrography embraces all the phenomena and material characters of rocks, as well as the theories regarding their origin and the relations between the rocks of the earth and the problems of geodynamics. Knowledge of the composition, mode of occurrence, and distribution of igneous rocks should contribute materially to the elucidation of those problems in geology which are concerned with the constitution and behavior of the outer and inner portions of the earth.

For many years some geologists and petrologists have been convinced that the various kinds of igneous rocks in different parts of the world, both volcanic outflows and intruded bodies, are so intimately related to one another within each region that they must have been derived from some parent lava, or rock magma, by processes of physicochemical differentiation; and further, that in different regions of the earth the series of igneous rocks in each possess chemical and mineral